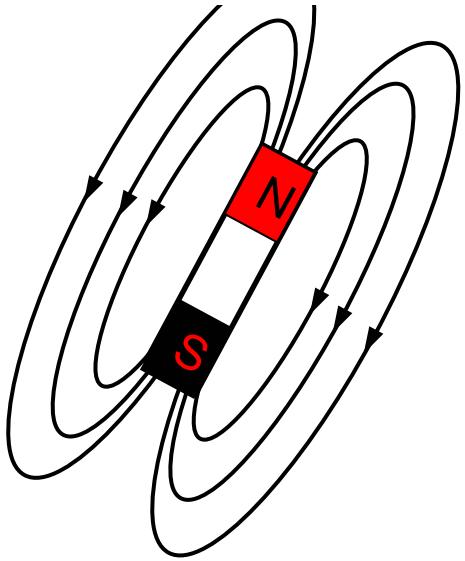
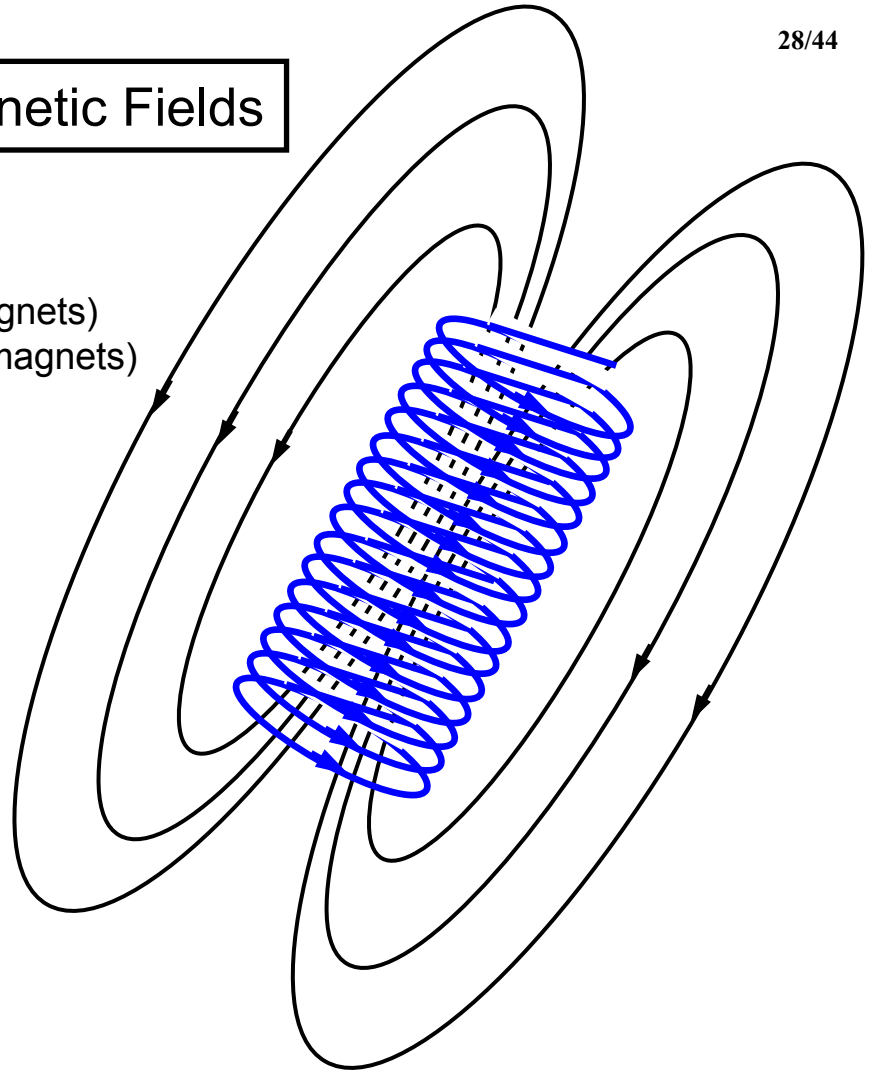
Challenges in Producing High Magnetic Fields

Permanent Magnets

0.4 gauss	Earth's Magnetic Field
600 gauss	Iron-Oxide Magnets (refrigerator magnets)
4,000 gauss	Neodymium-Iron-Boron (rare earth magnets)

--- This is near the limit for permanent magnets





Electromagnets

--- cooling problems (the wire heats up)

450,000 gauss	Hybrid DC Magnet (NHMFL-Tallahassee)	***(hours)***

--- ignore the cooling problem

800,000 gauss	Pulsed Magnet (NHMFL-Los Alamos)	***(milliseconds to seconds)***

Challenges in Producing High Magnetic Fields

Pressure Under Water

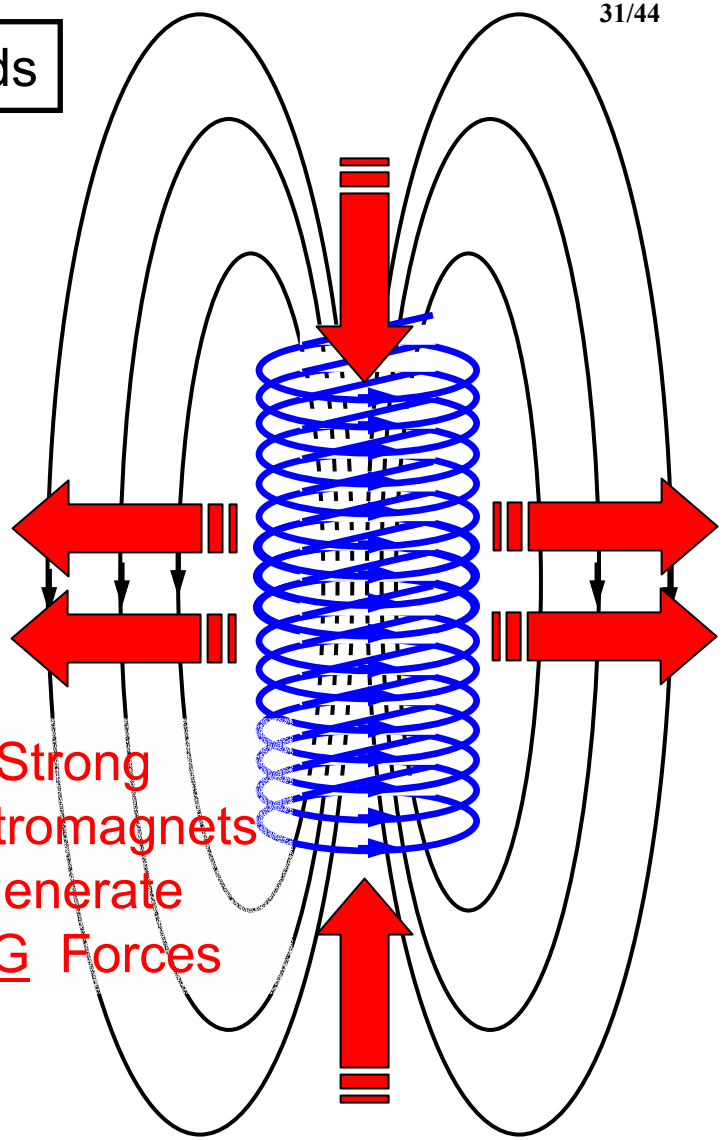
12 feet	**Ears**	**6 psi**
(pounds per square inch)		
2000 feet	**Submarine**	**1000 psi**
12,000 feet	**Ocean Floor**	**6000 psi**

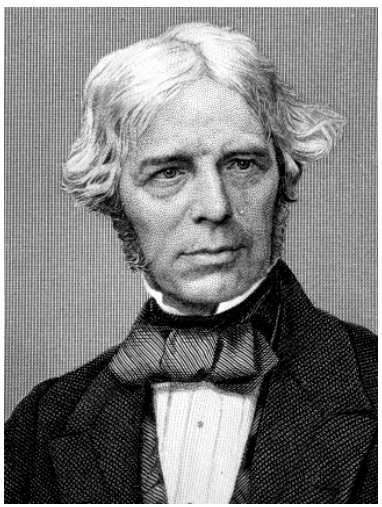
Pressure inside Powerful Electromagnets

800,000 gauss **Pulsed Magnet** **200,000 psi**

(which equals 130 kg per square millimeter)

(which is more pressure than most materials can handle)



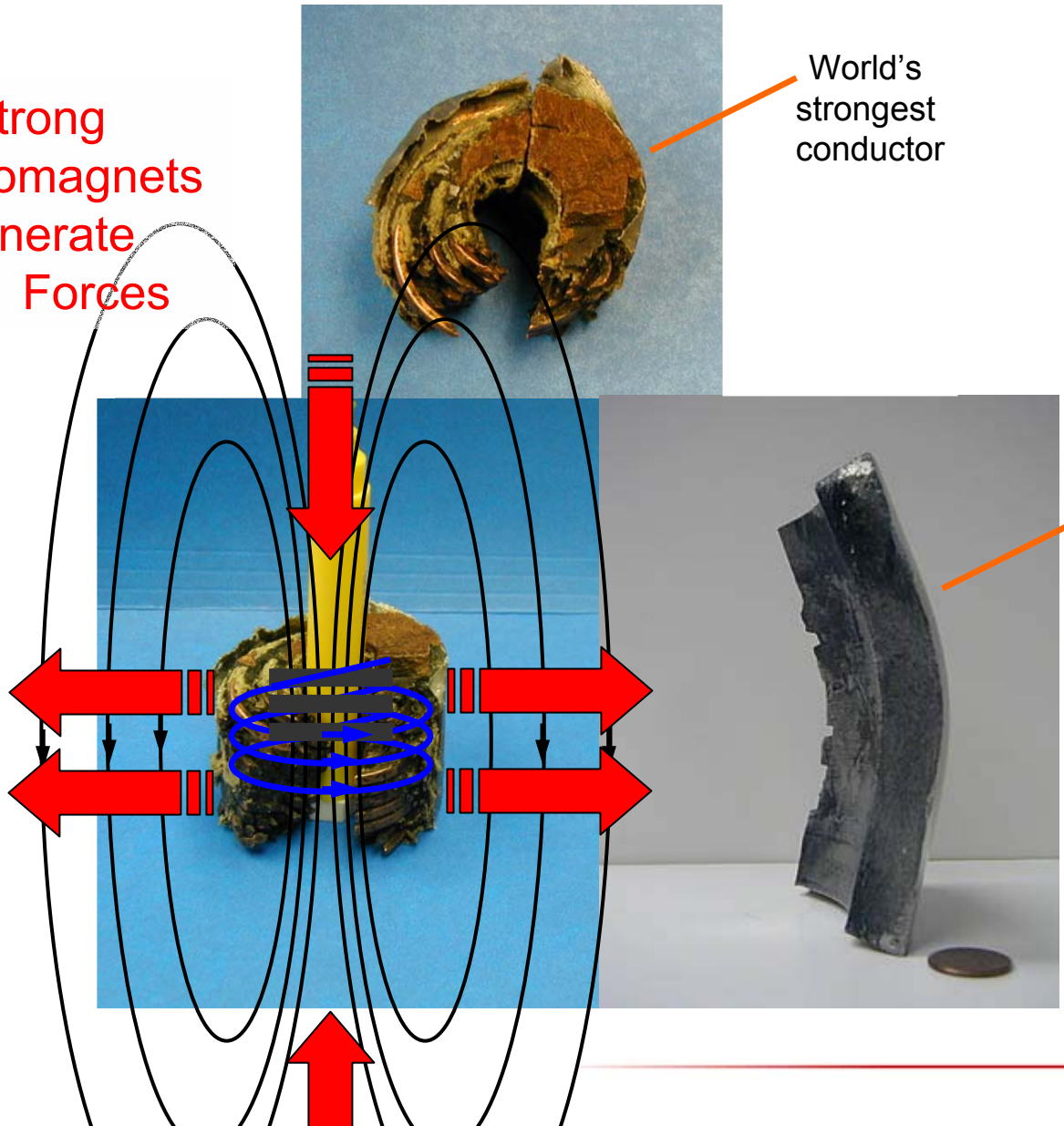


Michael Faraday

1821-31 Discovered that Electricity and Magnets together can produce Motion.

Challenges in Producing High Magnetic Fields

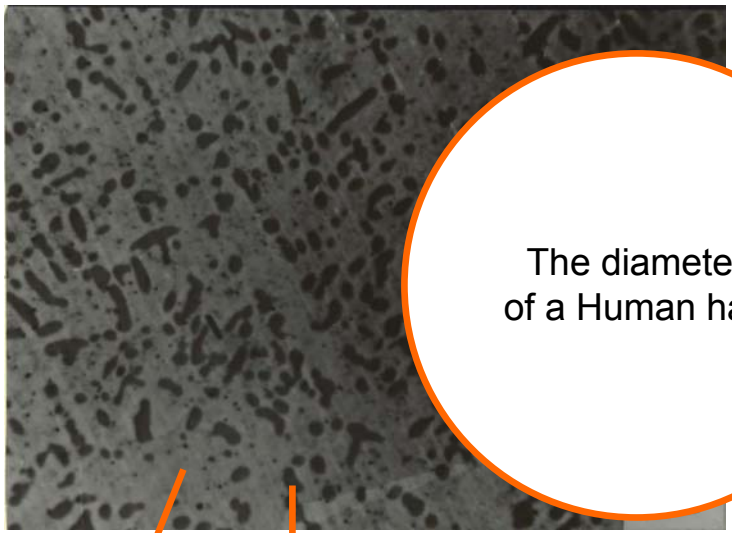
Strong Electromagnets Generate BIG Forces



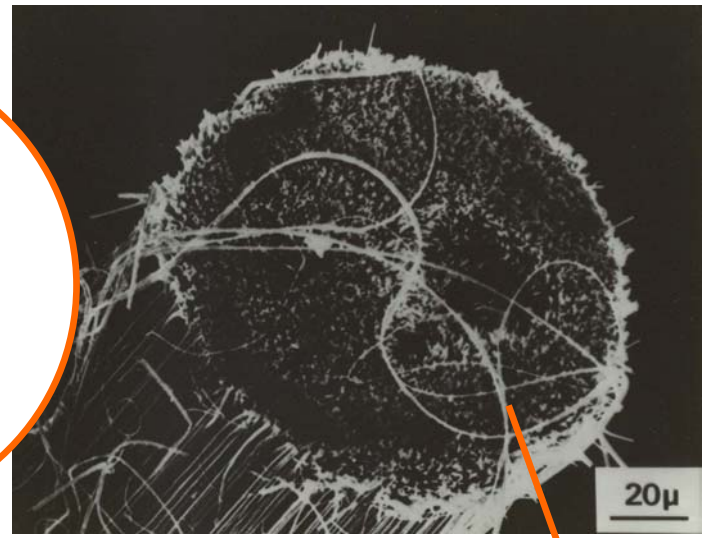
World's strongest conductor

World's strongest steel

Challenges in Producing High Magnetic Fields

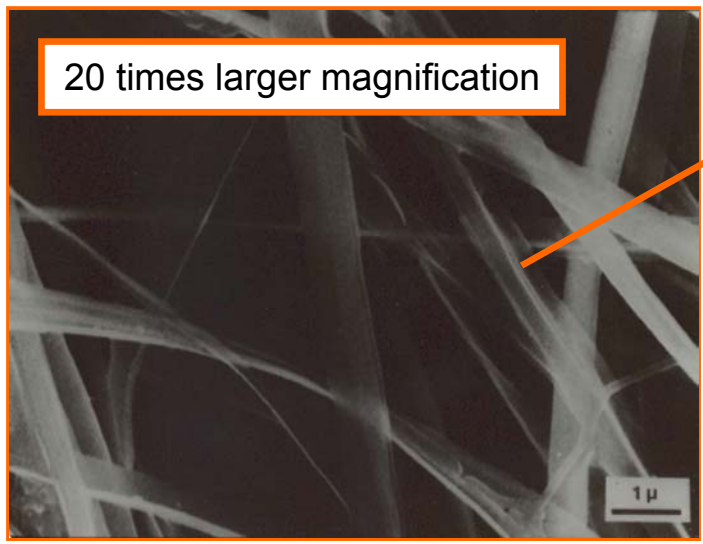


The diameter
of a Human hair



80% Copper

20% Niobium Droplets



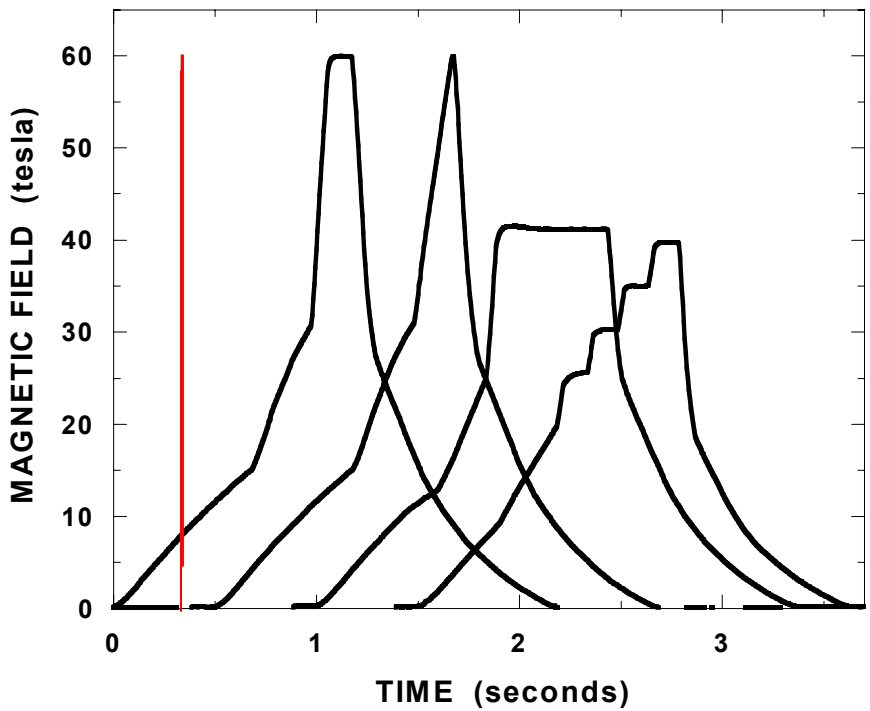
Niobium Ribbons

The Niobium ribbons work
(sort of)
like rebar in cement

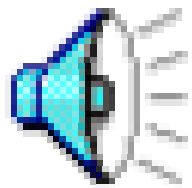
600,000 gauss Long-Pulse Magnet

Pushing the materials envelope
Unique 1.4 Billion Watt power system for pulsed magnets

First-ever capability to shape
- 600,000 gauss magnet pulses



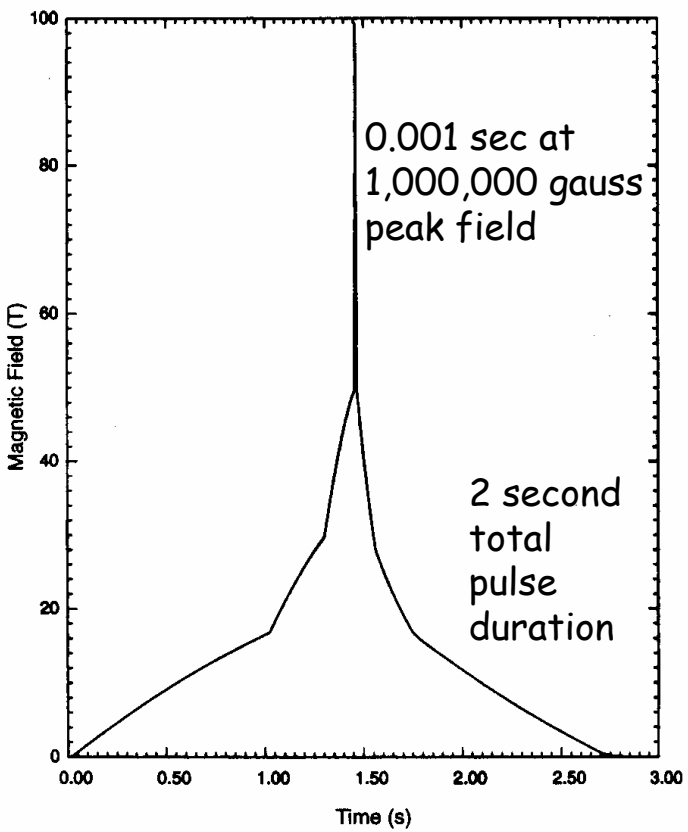
Following OSHA and other External Safety Reviews...
- All personnel evacuate the building before a pulse
- Generator operations computer monitored
- Pulse sequence is halted if any anomalies are found

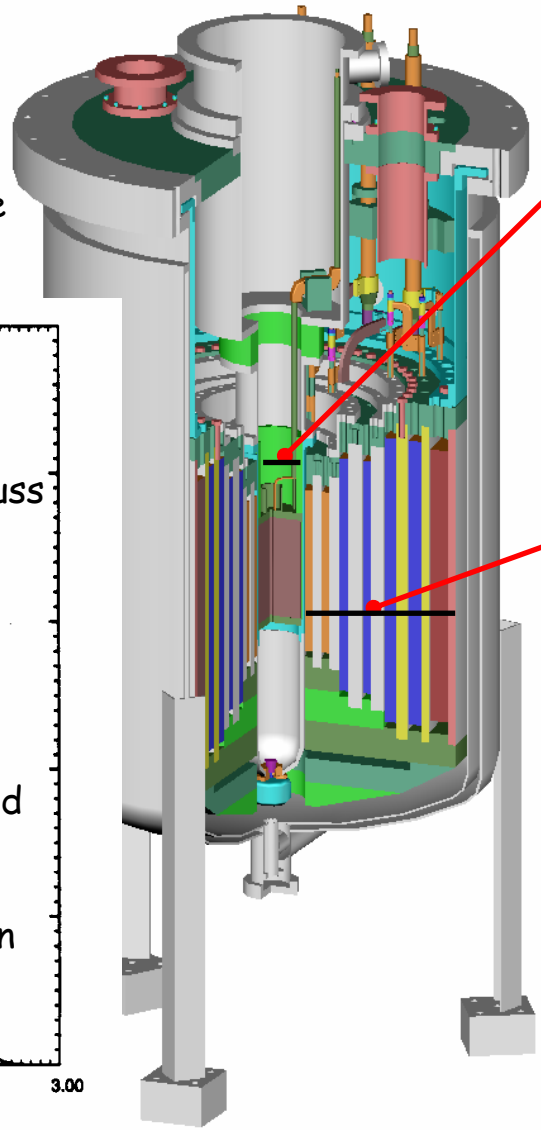


NHMFL's 1,000,000 Gauss Multi-Shot Magnet

Specifications

1,000,000 peak field
1/2 inch diameter bore
Pulse every hour





Insert Coil 530,000 gauss
(2 MJ peak energy)
(National Science Foundation)

Outer Coil 470,000 gauss
(125 MJ peak energy)
(Department of Energy)

1 meter

Challenges in Producing High Magnetic Fields

Permanent Magnets

0.4 gauss	Earth's Magnetic Field
600 gauss	Iron-Oxide Magnets (refrigerator magnets)
4,000 gauss	Neodymium-Iron-Boron (rare earth magnets)

--- limit of permanent magnets

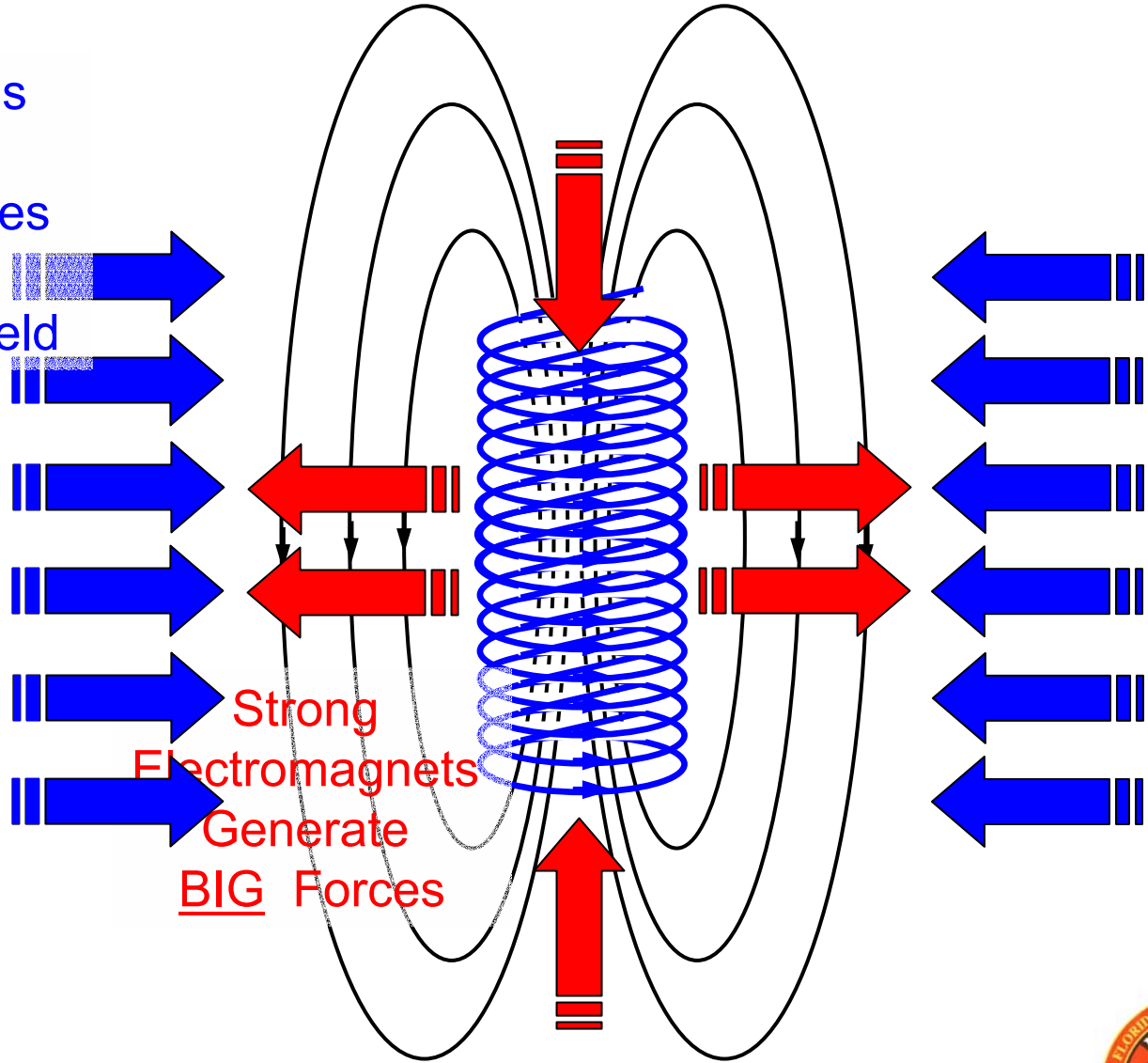
Electromagnets

450,000 gauss	Hybrid DC Magnet (NHMFL-Tallahassee)	*--- cooling and pressure problems (hours)*
800,000 gauss	Pulsed Magnet (NHMFL-Los Alamos)	*--- ignore the cooling problem (milliseconds to seconds)*
8,000,000 gauss	Flux Compression Magnet (Ancho Canyon-Los Alamos)	*--- ignore the pressure problem (microseconds)*

....TOO MUCH PRESSURE FOR ANY MATERIAL TO WITHSTAND....

Challenges in Producing High Magnetic Fields

Use Explosives
to Generate
BIGGER Forces
to Squeeze
the Magnetic Field



Ancho Canyon Movie.... "six months work is about to go up in smoke"

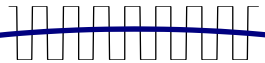
Have only microseconds

Making Measurements Rapidly

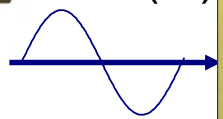
Each experiment lasts 0.01 seconds.... One measurement every 0.0000001 seconds.

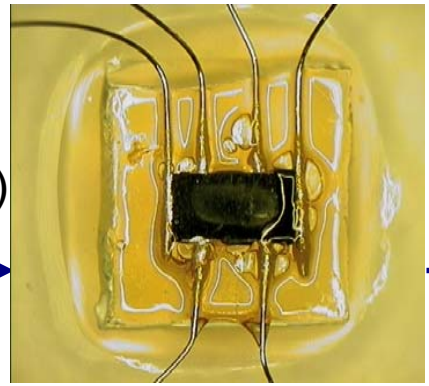
NHMFL Dual Synthesizer

Synchronous Clock (n x f)



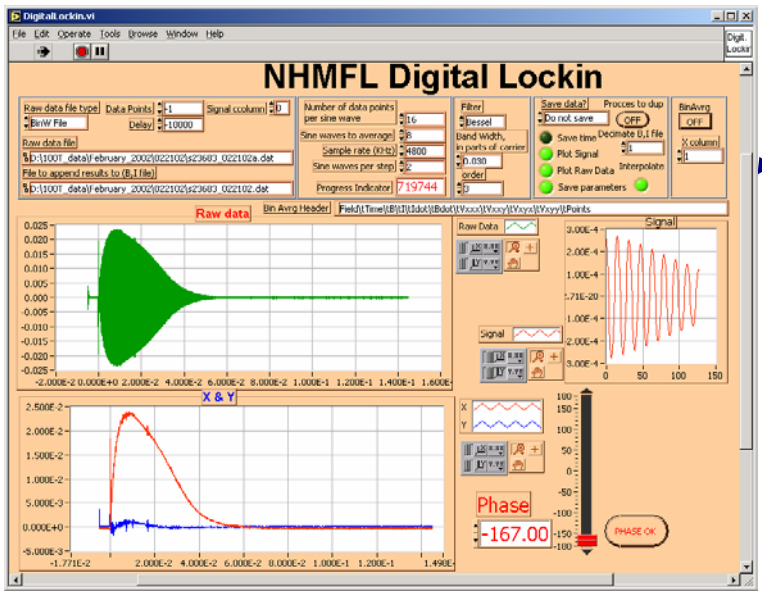
Drive (f)





Signal

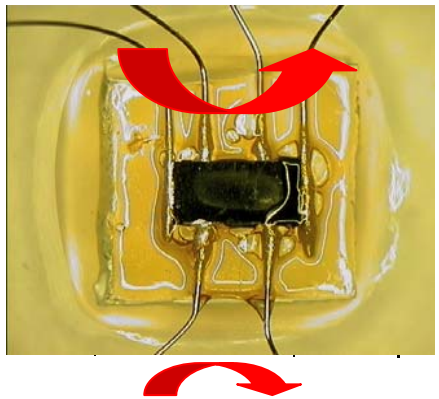
Digitizer



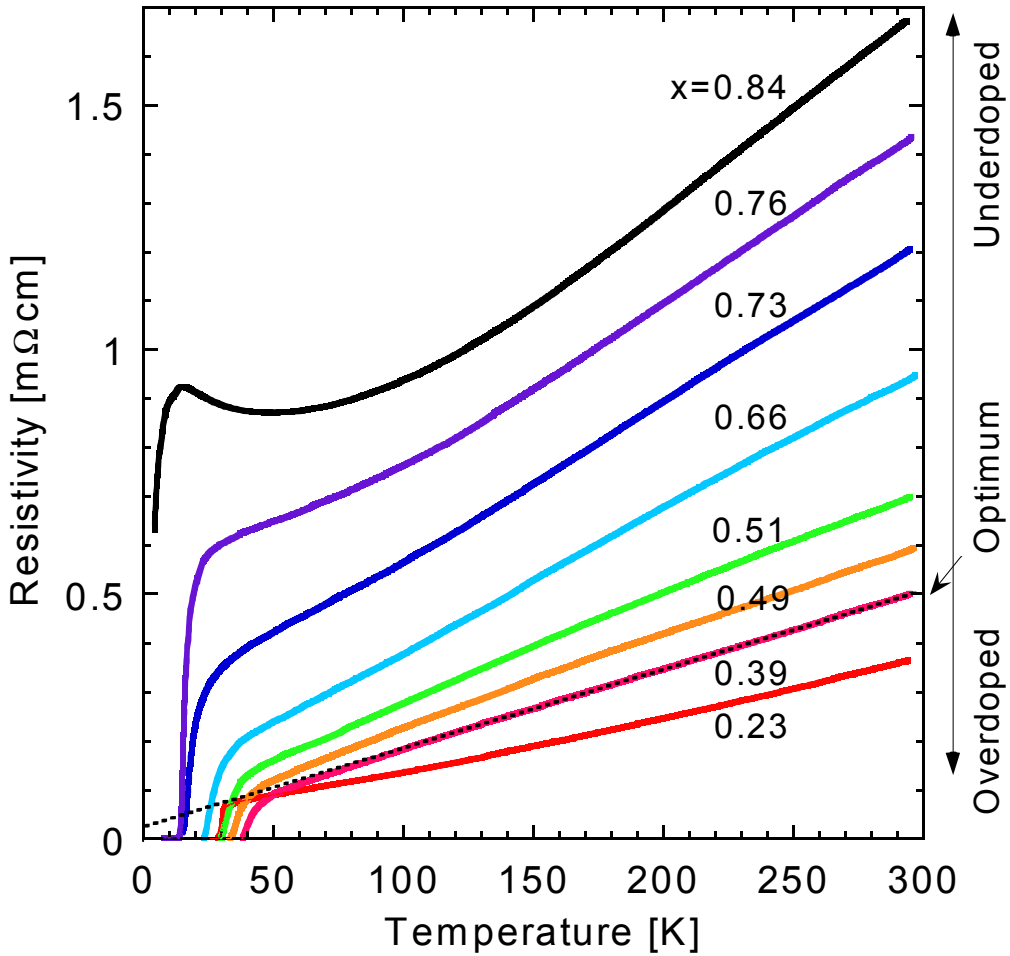
Computer

Experiments on High Temperature Superconductors

Put electricity
through the sample



Measure the voltage...
...the energy lost
by the electricity
in the sample
(heats up the sample)



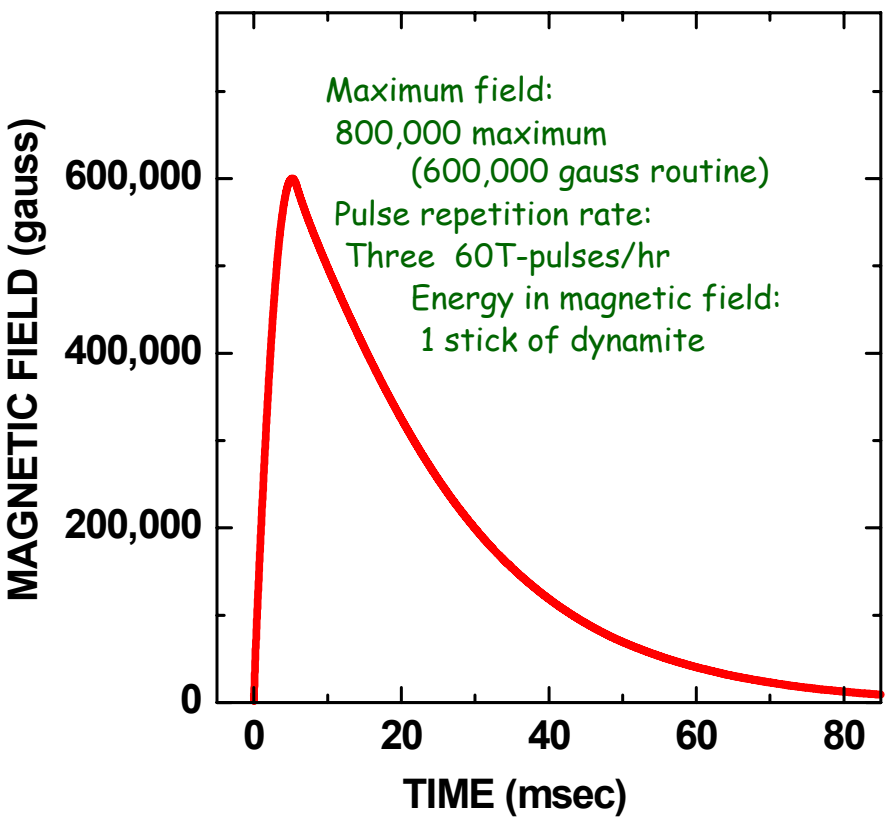
Crystals from heavily underdoped to moderately overdoped

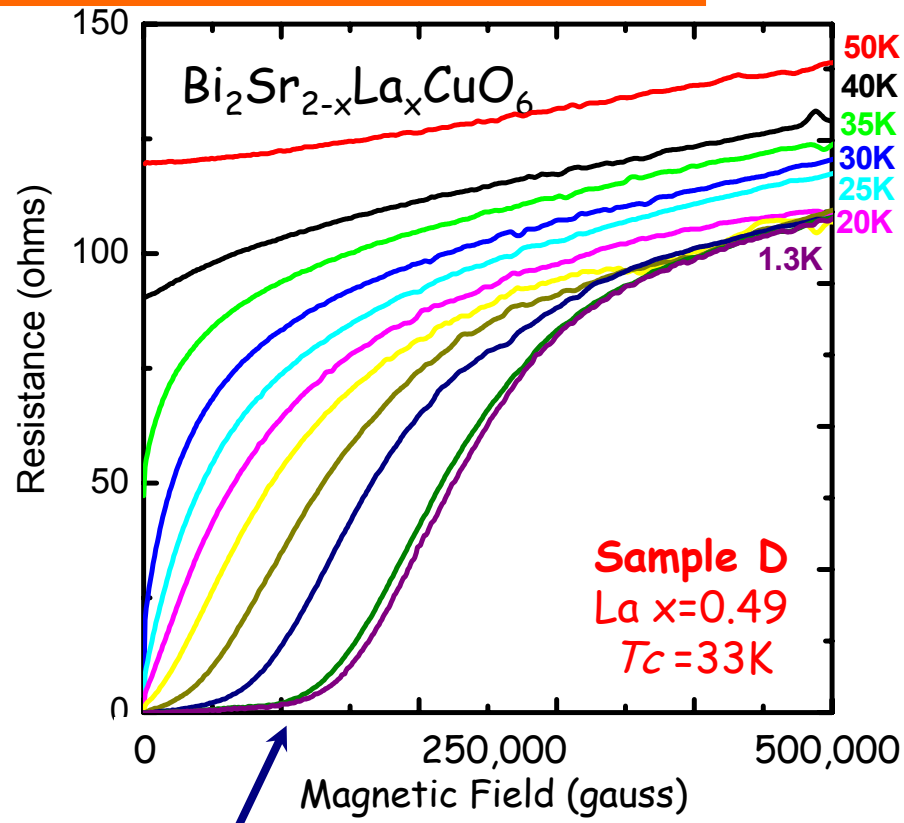
What is the behavior at low temperatures?

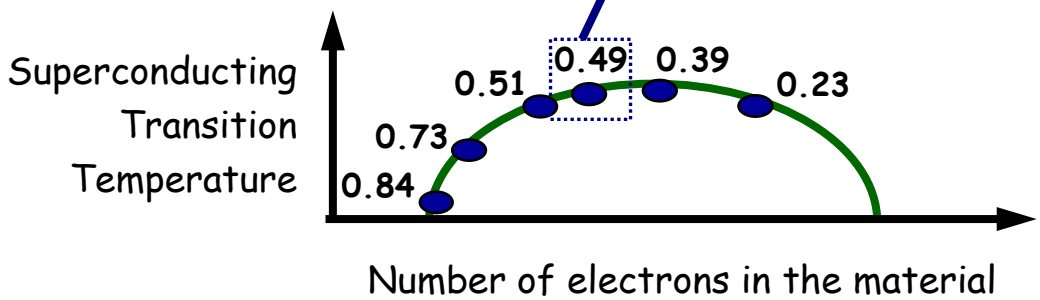
Samples grown at Central Research Institute of Electric Power Industry, Tokyo, Japan

La-doped Bi-2201 Single Crystals $Bi_2Sr_{2-x}La_xCuO_{6+\delta}$

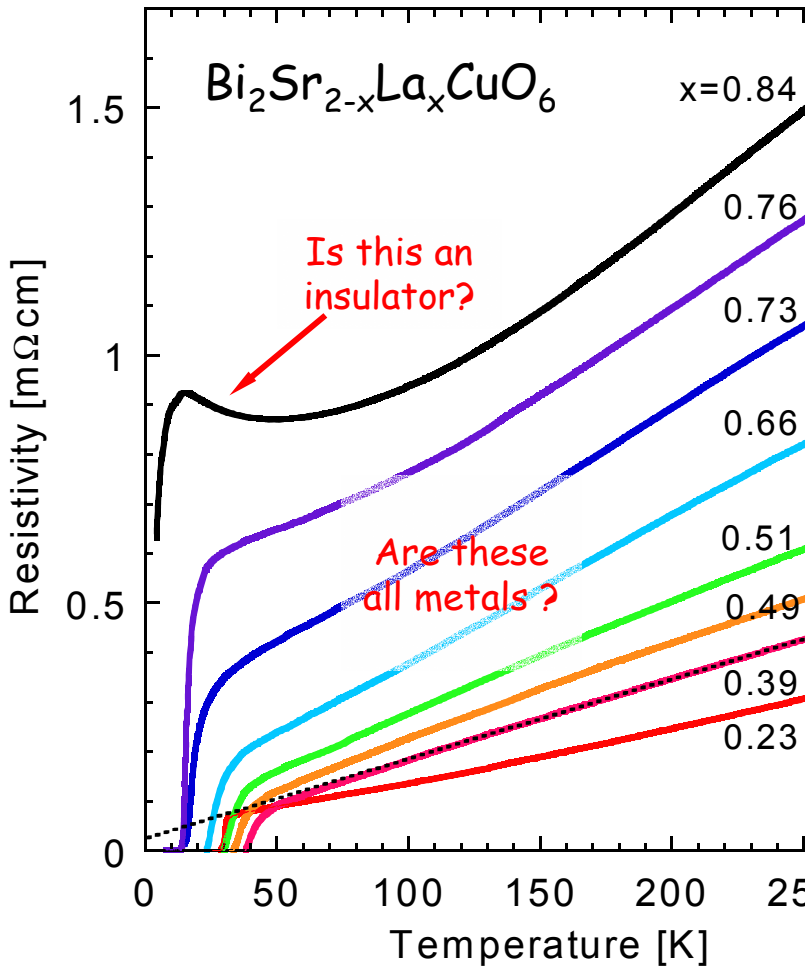
600,000 gauss magnetic field fully suppresses superconductivity

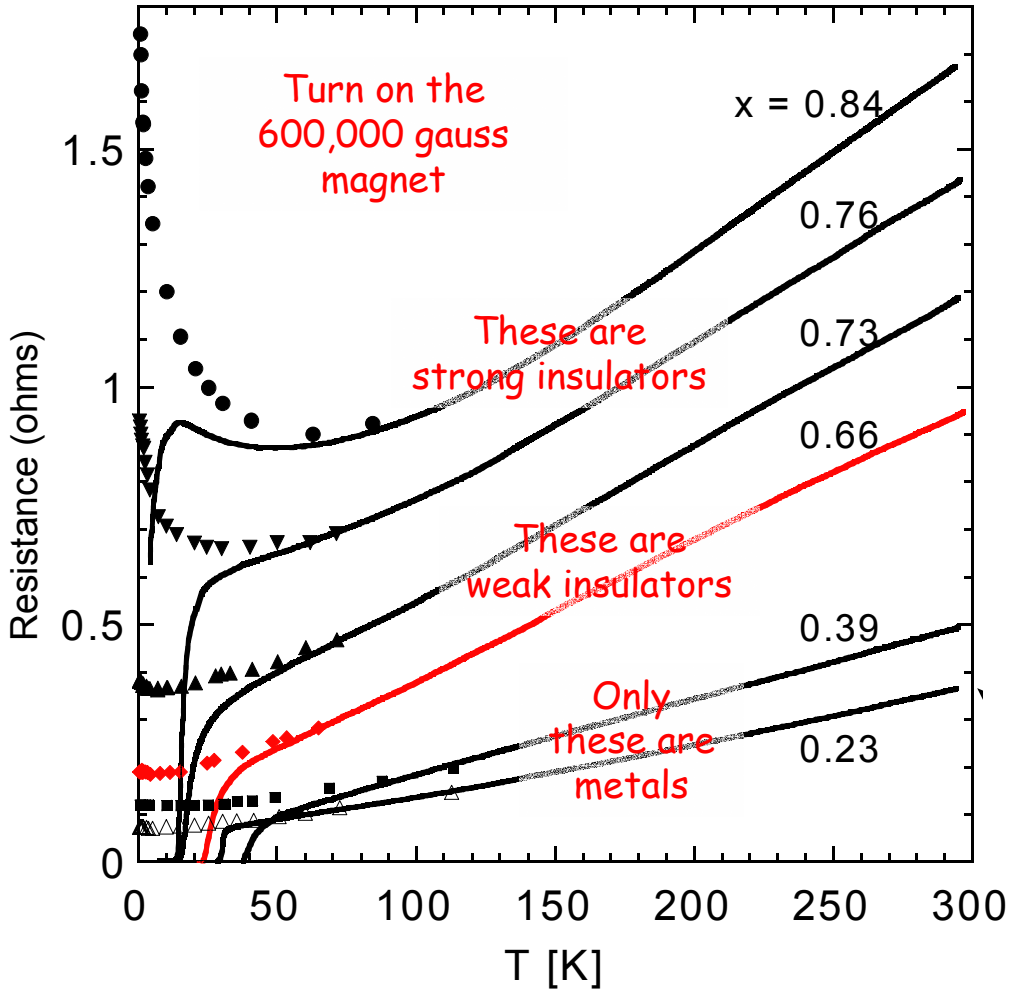






Using the 600,000 gauss Magnet to Suppress Superconductivity to Reveal the Low-Temperature Normal State

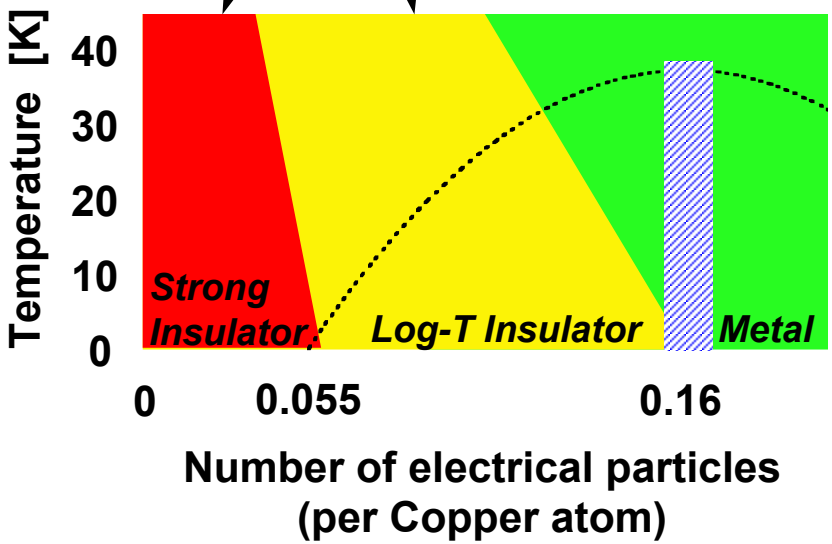


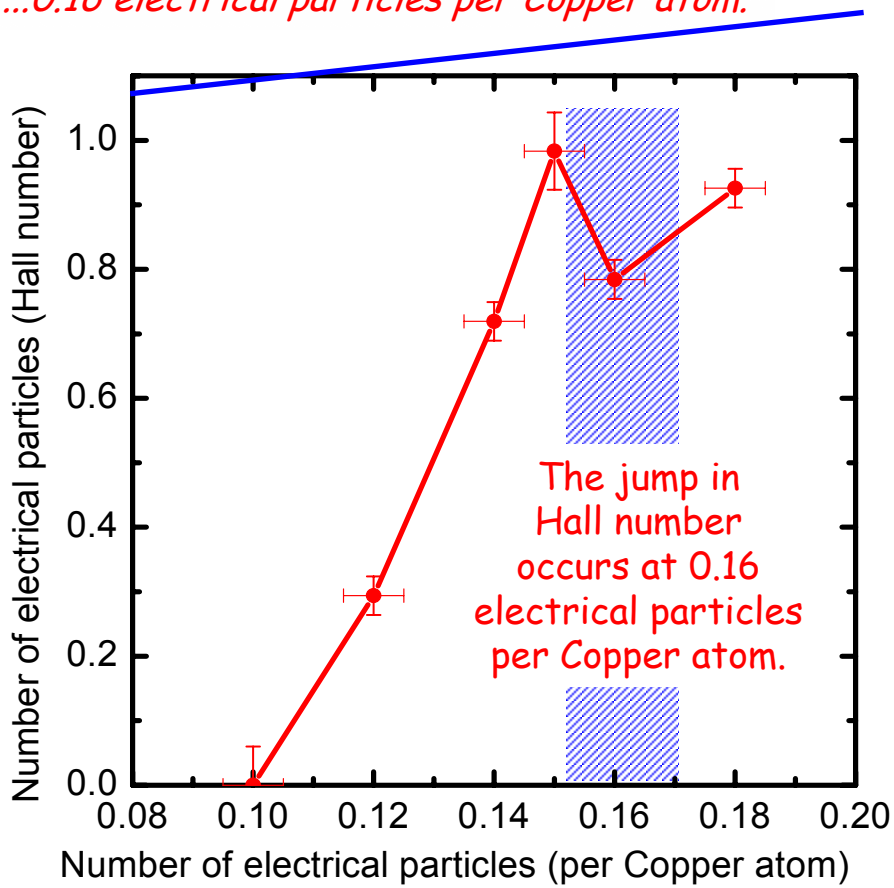


S. Ono, et al, Physical Review Letters 85, 638 (2000)

Conclusions: Insulator-Metal Crossover in the Low-Temperature Normal State

The highest superconducting transition temperature occurs at....
.... 0.16 electrical particles per Copper atom.
The insulator-metal crossover occurs at.... *....0.16 electrical particles per Copper atom.*

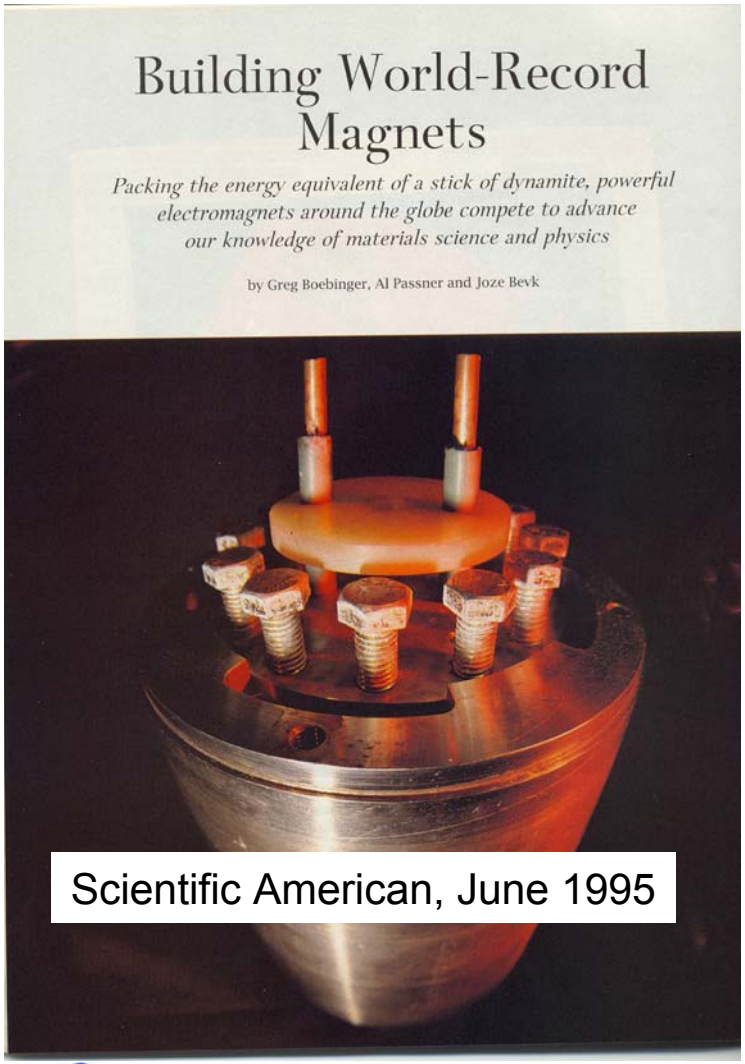




What does this mean?
No one knows yet.

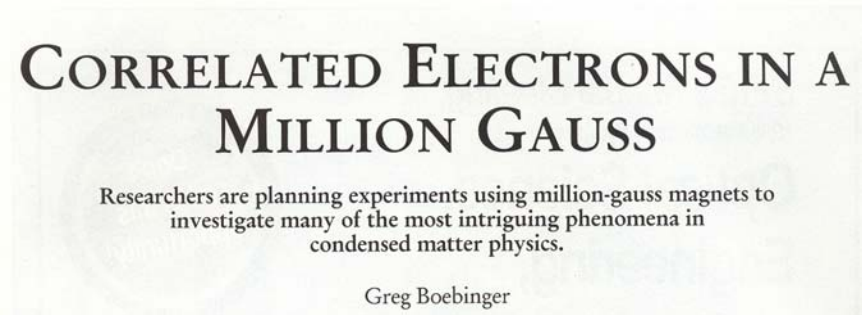
We do experiments so that eventually
only one theory of high-temperature superconductivity
can explain all the measurements....

If you want to read more about Magnets and Magnetism...



Scientific American, June 1995

Physics Today, June 1996



Driving Force, the Natural Magic of Magnets
by James D. Livingston
Harvard University Press, 1996
ISBN 0-674-21644-X
QC757.L58 1996 $24.95

Hidden Attraction, the Mystery and History of Magnetism
by Gerrit L. Verschuur
Oxford University Press, 1993
ISBN 0-19-506488-7
QC753.5.V47 1993 $25.00

Los Alamos NATIONAL LABORATORY

NHMFL FLORIDA STATE UNIVERSITY LOS ALAMOS UNIVERSITY of FLORIDA